

Potential Evapotranspiration Networks in Texas: Design, Coverage and Operation

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Introduction

Agricultural irrigation crop is the largest user of water in the Texas High Plains, a region with over 4 million acres of irrigated crop production. Annual crop production receipts in the northern 26 counties of the Texas Panhandle exceed \$770 million, and the estimated agribusiness economic impact exceeds \$3.25 billion (Amosson and Ledbetter, 1996). This region is dependent on the Ogallala Aquifer for the majority of its water supply, but this incredible water resource is declining. Enormous changes in irrigated agriculture in this region in the past 20 years that have dramatically decreased the water applied per unit land area. Nevertheless, some areas in the region are still experiencing water table decline rates exceeding two feet per year. At the USDA-ARS station at Bushland, most of our well hydrographs now show water table decline rates less than one foot per year, but well yields still have declined appreciably as the aquifer saturated thickness has declined. Advanced irrigation scheduling is one technology not widely used in the Texas High Plains that can further reduce irrigation applications and help sustain irrigation in this important region.

Development of PET Networks: An Overview

In 1992, a Texas Agricultural Experiment Station (TAES) and Texas Agricultural Extension Service (TAEX) team at Lubbock (Seymour et al., 1994) developed the South Plains PET Network around the three weather stations at Lamesa (AgCares), Lubbock, and Halfway. They faxed daily PET (Potential EvapoTranspiration) and heat unit information to subscribers and distributed it to mass media. They developed spreadsheet programs to use these data for irrigation scheduling, and extensively worked on education and training of growers to use this technology.

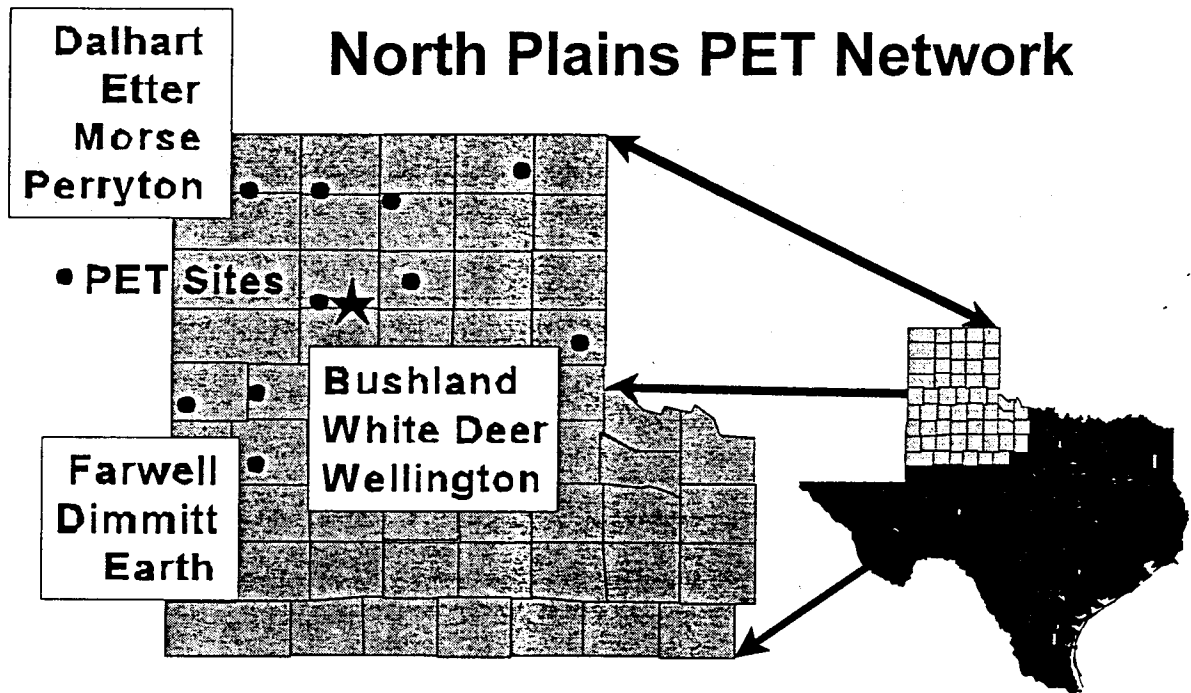
In 1994, a team of engineers and scientists representing the Texas Agricultural Experiment Station, Texas Agricultural Extension Service, and USDA-Agricultural Research Service (ARS) at Amarillo/Bushland/Elter (Marek et al., 1996) developed a similar weather station network, called the North Plains PET Network (NP-PET), to serve the northern Texas Panhandle. Their development included input and feedback from growers and consultants prior to the finalization of the output information and format. Currently, the NP-PET operates 10 separate weather stations across the central and northern Texas Panhandle. The NP-PET network sends more than 325 faxes early each morning to a wide range of subscribers.

Although the North Plains and South Plains networks are separate and distinctly different, they collaborate and use similar methods. Both networks maintain a web site where the faxes and archived data can be electronically obtained. For example, the NP-PET web site provides archived data, which includes the hourly data and its daily statistics (maximums, minimums, totals, etc.).

Other weather networks are in Texas and surrounding states. A Texas PET network was developed beginning in 1995 by the Texas Agricultural Extension Service at Texas A&M University (Fipps, 1998). The Texas PET now has more than 19 station sites at locations ranging from the Lower Rio Grande Valley to the Coastal Bend and Edwards aquifer regions to North and Central Texas.

Another network comprised of 22 weather stations was developed in the Coastal Plains area by TAES, Corpus Christi (Landivar, 1998). It evolved out of a need for site specific and regional weather data to run cotton and sorghum simulation models in use in that area.

The Oklahoma MesoNet (Brock et al., 1995, and Elliott et al., 1998) may be the most extensive such example. Plans are being made for a Texas MesoNet for more complete electronic statewide weather information coverage.



North Plains-PET Network Design and Operation

The NP-PET sites are shown in Fig. 1. The northern tier of stations are located at Dalhart, Etter, Morse, and Perryton. The central tier of stations are located at Bushland, White Deer and Wellington, and the southern tier of stations are located at Farwell, Dimmitt, and Earth. The NP-PET acquisition computers are located at USDA-ARS, Bushland and interrogate each station after midnight to acquire the weather data from the previous day. The computers process the data, computing PET, heat units (growing degree days or GDDs), and the respective crop water use for corn, cotton, wheat, grain sorghum, soybean, and peanut. These data are used to format a fax sheet for each weather station (and its associated crops; some stations only have certain crop data segments). Then, the computers automatically send the fax sheets to each subscriber for that station before 6:00 a.m. The computers also upload the fax files and the hourly processed weather data files to a central server for access on the world wide web as follows: (<http://amarillo2.tamu.edu/nppet/petnet1.htm>).

Table 1 illustrates a daily fax sheet for the Farwell, TX, NP-PET weather station (see <http://amarillo2.tamu.edu/nppet/data/new/farwell/dailyfax/>). On this date, which represents a transition period between winter and summer crops, only data on wheat, corn, and peanut are reported, but cotton and soybean data began appearing on May 1 and May 15, respectively. The upper section of Table 1 gives a mini 3-day climate summary with the daily PET value, maximum and minimum air temperatures, minimum soil temperatures for the 2 and 6 inch depths, precipitation and GDD's for various crops. The 10-day average minimum soil temperatures are also given as a crop planting guide. Table 1 gives specific data for each crop (in season) that we report for that specific weather station site. Each crop's water use is bracketed for four planting dates that generally cover the expected range of planting dates. The accumulated GDDs from sowing date until the current day are given for each sowing date along with a predicted crop development stage and the current day's ET, past 3-days' ET, past 7-days' ET, and the accumulated season's ET (water use) since planting. For corn, grain sorghum, and peanut, ET and crop development are estimated for two types of typical long and short-season cultivars (hybrids for corn and grain sorghum and varieties for peanut). For cotton, wheat, and soybean (midgroup IV type) only one cultivar type is simulated. We only simulate "well-watered" and "normal" crops (i.e., assuming no insect, diseases, or weed pest limitations) for "high level" production practice.

The bottom section of the fax sheet contains limited space for remarks, messages, notices, and alerts. The notices on this fax sheet highlight our web site addresses and our "standard" winter disclaimer about the measured precipitation (our rain gauges are not capable of accurately recording snow and/or ice).

Many users need more detailed data for their particular applications, especially consultants and industries that may be using other prediction models. Therefore, all the NP-PET hourly data (as well as the fax sheets) are available on the TAMU Agricultural Research and Extension Center at Amarillo web server (see <http://amarillo2.tamu.edu/nppet/petnet1.htm>). These data and fax files are updated daily, but then are compacted into 10-day "zip" files after a short period of time to save space and for faster downloading by users. Zip files are designated for example as *fdal9810.zip* which includes faxes for dalhart in 1998 for days 100 thru 109. *fdal9811.zip* would include faxes of days 110 thru 119 in 1998.

Table 2 illustrates the hourly data file for the Farwell, TX, NP-PET weather station site (<http://amarillo2.tamu.edu/nppet/data/new/farwell/hourly/>). All the NP-PET hourly data are measured and recorded in the S.I. (System International) unit system for integrity and consistency. Conversion factors into common English units are widely available. The file header gives station data and standard astronomical data for that day. The data columns represent hourly means (or a total as in the case for precipitation) of the data and derived parameters. The bottom section contains daily sums (an integrated value for solar radiation), daily averages, and maximums and minimums and the time of occurrences for specific column variables.

A dramatic increase in PET occurred from 0.27 to 0.37 in./day on April 23rd and April 24th (Table 1). A PET value of 0.37 in./day is "fairly" large but not uncommon for West Texas. Air temperatures were only a little warmer on April 24th and the amount of solar radiation (sunshine) was quite similar to the previous day. The main differences were the drier air (mean relative humidity of 31% on 4/24/98 and 42% on 4/23/98) and the much stronger winds (mean of 12.1 miles/hr on 4/24/98 and 7.1 miles/hr on 4/23/98). Our data and experiences (together with these NP-PET data) have illustrated that such occurrences are not uncommon in this region, but that they can greatly impact water management decisions in the spring.

North Plains PET Network Weather Station, Farwell, TX

Date	PET in.	Temperatures (F)		Soil Min.		Prec. in.	Growing Degrees Days (F)							
		---Air-- Max Min	2in. 6in.	Crn	Srg		Pnt	Cot	Soy	Bet	Wht			
11/06/98	.02	48 41	46 47	0.01	0	0	0	0	0	0	0	0	12	
11/07/98	.12	63 38	45 47	0.01	0	0	0	0	0	0	0	0	18	
11/08/98	.13	70 32	42 45	0.00	0	0	0	0	0	0	0	0	19	
10-day avg min soil temp		47 49												

WHEAT			Water Use			Seas.
Seed Date	Acc GDD	Growth Stage	Day	3day	7day	
08/15	2547	Tiller	.06	.04	.03	7.8
09/10	1596	Tiller	.06	.05	.04	5.1
10/01	852	Tiller	.06	.05	.04	2.7
10/15	515	Emerged	.06	.05	.04	1.3

ARS-BUSHLAND WEB ADDRESS -- <http://www.cprl.ars.usda.gov/>

North Plains PET Home Page is on the web
<http://amarillo2.tamu.edu/nppet/petnet1.htm>

Station: FARWELL, TX Long 103 deg 2 min Lat 34 deg 26 min
 Date: 11/08/98 Year/DOY: 98312
 Sunrise 718 Sunset 1753 Daylight time = 10 hours 35 minutes

Time	Rs	Ts2	Ts6	Tair	TDew	RH	VP	VPD	WSpd	Wdir	SDd	PREC
CST	W/m^2	C	C	C	C	%	kPa	kPa	m/s	deg	deg	mm
100	-0.0	6.9	9.2	3.6	2.4	92	0.73	0.06	2.2	116	13	0.00
200	-0.0	6.6	8.9	2.4	1.8	96	0.70	0.03	1.6	114	11	0.00
300	-0.0	6.3	8.7	1.3	1.1	99	0.66	0.01	1.1	104	13	0.00
400	0.0	6.0	8.4	0.9	0.8	100	0.65	0.00	1.3	109	12	0.00
500	0.0	5.8	8.2	0.7	0.7	100	0.64	0.00	1.0	112	8	0.00
600	0.0	5.5	7.9	-0.0	-0.0	100	0.61	-0.00	0.7	111	16	0.00
700	0.0	5.4	7.7	0.8	0.9	100	0.65	-0.01	0.7	152	16	0.00
800	24.5	5.7	7.6	2.7	2.8	100	0.75	-0.00	1.8	156	12	0.00
900	155.0	5.8	7.5	3.8	3.7	99	0.80	0.01	2.3	168	15	0.00
1000	216.6	6.5	7.5	5.5	5.2	98	0.89	0.02	2.9	200	15	0.00
1100	300.6	8.0	7.8	6.5	6.2	98	0.95	0.02	2.8	207	14	0.00
1200	440.8	9.5	8.2	9.3	6.8	85	0.99	0.18	3.0	213	14	0.00
1300	596.5	10.9	8.8	13.4	7.3	67	1.02	0.52	3.4	230	17	0.00
1400	634.5	12.5	9.6	17.1	6.9	51	1.00	0.96	4.1	253	19	0.00
1500	504.2	13.4	10.3	20.0	2.8	32	0.75	1.58	5.7	262	13	0.00
1600	460.9	13.4	10.9	20.7	2.0	29	0.70	1.73	6.1	268	13	0.00
1700	234.3	13.0	11.2	20.3	2.4	30	0.72	1.66	4.9	278	12	0.00
1800	51.4	12.1	11.4	17.5	2.6	37	0.74	1.27	2.6	265	12	0.00
1900	-0.0	11.1	11.3	12.7	3.1	52	0.77	0.71	1.7	263	8	0.00
2000	-0.2	10.3	11.1	12.4	3.3	54	0.77	0.67	2.7	250	11	0.00
2100	-0.2	9.7	10.8	11.9	3.3	56	0.77	0.62	2.3	265	21	0.00
2200	-0.2	9.2	10.6	8.4	3.6	72	0.79	0.32	1.2	287	26	0.00
2300	-0.2	8.7	10.3	7.7	3.5	75	0.79	0.27	1.3	280	16	0.00
2400	-0.1	8.6	10.1	7.4	4.0	79	0.82	0.21	1.4	271	14	0.00
Sum	13.0 MJ											0.00
Avg		8.8	9.3	8.6	3.2	75	0.78	0.45	2.45	218	70	
Max	975.2	13.5	11.4	21.2	8.3	100	1.10	1.85	9.20			
Time	1228	1529	1725	1519	1228	650	1228	1516	1535			
Min		5.3	7.5	-0.2	-0.2	26	0.60	-0.01				
Time		612	900	609	530	1516	530	652				

The USDA-ARS ET team at Bushland has measured and documented many extremely high ET rates for wheat, corn, alfalfa, and grass that are as large at Bushland as any place in the world. In fact, often these extreme events occur in spring and early summer in the Texas High Plains when wind speeds are strong, the air is drier, and the skies are relatively clear as contrasted to summer months when temperatures may be warmer, but when more clouds occur (afternoon and evening convective storms), winds are much calmer, and the air is more humid.

NP-PET Methods

The NP-PET network uses GDD (growing degree days) as the thermal time parameter for computing crop coefficients (Kc) and for estimating crop development rates. GDDs are computed as

$$\text{GDD} = (\text{Tmax} + \text{Tmin})/2 - \text{Tbase}$$

subject to these constraints:

if $\text{Tbase} \geq \text{Tmax}$, then Tmax is set equal to Tbase
 if $\text{Tmax} \geq \text{Tupper}$, then Tmax is set equal to Tupper
 if $\text{Tbase} \geq \text{Tmin}$, then Tmin is set equal to Tbase
 if $\text{Tmin} \geq \text{Tupper}$, then Tmin is set equal to Tupper

where Tmax and Tmin are the daily maximum and minimum air temperatures, Tbase is the GDD base temperature, and Tupper is an upper cut-off threshold temperature. Table 3 summarizes the GDD crop constants used by the NP-PET programs. All computations are made in °C and converted to °F scales for the fax sheets (see Table 1). The NP-PET network computes PET for a cool-season grass type (about 4-5 in. tall) using standard procedures as outlined by Allen et al. (1994) that are recommended world-wide. These equations are based on the grass reference ET equations. A grass reference PET equation was chosen because it could, perhaps, be explained and visualized easier by our expected urban clientele. In fact, the Potter and Randall County Master Gardener Program now routinely uses the PET data to compute lawn grass water use for the Water Smart project in Amarillo and Canyon. The PET values for bluegrass, buffalo, and Bermuda grass are computed and published daily (May through November) in the Amarillo Globe News on page 2 with all the other weather news data. Actual water use rates for the NP-PET crops are computed as

$$\text{ET} = \text{Kc} * \text{PET}$$

where ET is the estimated actual crop water use rate (in./day), Kc is the mean crop coefficient and PET is the daily reference ET (in./day). The NP-PET network uses mean Kc values because our water use estimates are more "regionally generic" and not specific for any one farm or field. Crop consultants and farm advisors can use the PET data or the actual weather data (see Table 2) in more detailed crop growth or ET models that can provide a better representation of exact farm and even individual field conditions. The NP-PET Kc values were developed from research at Bushland by the ARS ET team. The mean Kc values used in our programs best represent sprinkler (center pivot) irrigation practices with frequent irrigations (3-4 day intervals) than graded furrow (less frequent irrigations), but that should not create a significant difference in the estimated crop ET values. The crop development models relate crop growth stages to accumulated GDDs. The Kc values are related to the crop growth stages as well by the accumulated GDDs. The NP-PET simple crop development models, Kc values, and PET methods are all being updated as new and improved data and procedures are developed.

Using The NP-PET Information

To be able to use this information, continued training and/or continuing education is needed. Faculty with TAEX and TAES, Texas A&M University (TAMU), and West Texas A&M University (WTAMU) all extensively use the NP-PET data in training and education programs.

Local data on field rainfall and irrigation are needed at a minimum. Other required data include the field's irrigation system capacity (flow rate per unit area) and/or the gross flow rate and an estimate of the system's "application efficiency." Crop data on sowing date and hybrid types are needed as well. It is probably better to match your actual

crop development status (in your field) with the fax sheet crop growth stage rather than relying solely on your sowing date.

To maintain a running water balance, the rainfall and irrigation quantities are compiled data by the user. The difference between the rain and crop ET must come from 1) previously stored soil water or 2) irrigations. Irrigations should be applied when the ET rates are lower to keep the soil water in the root zone replenished and so that a "relatively full" soil profile can be available when the crop growth reaches the critical periods like flowering and pod development for soybeans for example.

Although many irrigated areas have irrigation capacities that more than meet near "maximum" ET rates, most of the western Ogallala regions "stretch" their well capacities. If a marginal irrigation capacity is virtually used, then a producer is always trying to catch up and needing timely rains to "hopefully" achieve an acceptable yield. By knowing the crop ET needs (and as we obtain longer-term data gaining "expected or normal" ET rates), growers are in a much better position to make those critical strategic irrigation decisions and determine their acceptable levels of risk.

Impact Evaluation

The NP-PET Network was used by more than 325 growers, consultants and other in 1998. These users manage some 350,00-400,000 acres. In survey results, they reported an estimated water savings of 2 ac-in/ac/yr, which projects to an average annual groundwater savings of 62,500 acre feet/yr. Reduced fuel cost (natural gas) was \$10 million/yr and decreased engine and pump wear and tear amounted to \$8 million/yr. The total estimated savings to growers (\$18 million/yr) compares very favorably to approximate system operating cost less than of \$25,000/yr not including salaries of permanent faculty/scientists that support the system.

NP-PET Team

No one individual or agency is solely responsible for the NP-PET network, but requires a collaborative effort and support (financial and physical) from many agencies and personnel. Grants from the Texas Corn Producers Board, Texas Wheat Producers Board, High Plains Underground Water Conservation District No. 1, North Plains Ground Water Conservation District No. 2, Panhandle Ground Water Conservation District No. 3, Collingsworth County Underground Water Conservation District, and from other agencies (USDA-NRCS) and individual producer groups were instrumental in providing the necessary resources for system development, implementation and operation. For example, the Wellington weather station (Collingsworth County Underground Water Conservation District) was sponsored by the Salt Fork Conservation District of USDA-NRCS and other individual organizations.

The Texas Agricultural Experiment Station, Texas Agricultural Extension Service, and USDA-Agricultural Research team at Amarillo/Bushland/Etter provide the necessary faculty/scientists salaries and infrastructure support, and they have redirected certain water-related funds to support proper operation and maintenance. The multi-agency personnel involved with the NP-PET network are the following:

Texas Agricultural Experiment Station, Amarillo
 Thomas Marek, P.E., Research Engineer
 Dr. Gerald Michels, Jr., Professor of Entomology

Texas Agricultural Extension Service, Amarillo
 Leon New, P.E., Extension Agricultural Engineer
 Dr. Brent Bean, Extension Agronomist

USDA-Agricultural Research Service, Bushland
 Dr. Terry Howell, P.E., Research Leader and Agricultural Engineer
 Dr. Steve Evett, Agricultural Engineer
 Don Dusek, Agronomist

Several other USDA-ARS Water Management Research Unit personnel at Bushland were also involved with developing the ET system data upon which the NP-PET network is based.

The Texas PET Network

The original purpose of Texas ET, located in North, Central, West Central and South Texas, was to demonstrate the usefulness of PET for irrigation water management and conservation in both agriculture and urban landscapes (Fipps, 1998). Like the networks on the High Plains, the Texas ET Network uses the Penman-Monteith method for calculating PET from climatic data.

The Web Site (web address – <http://texaset.tamu.edu>) is designed as a comprehensive resource on PET and how to use PET for irrigation decisions. The Web Site provides daily PET rates and weather summaries of maximum and minimum temperature, minimum relative humidity, solar radiation, rainfall, and wind speed at 4 AM and 4 PM for each of the 19 stations. The Web Site has three calculators (separate ones for crops and turf, and a more advanced "interactive" calculator), so users can determine water requirements for themselves. These calculators also allow users to adjust water requirements based on the efficiency of their irrigation systems. "Pop-up" windows allow access to tables of Texas and FAO crop coefficients, turf coefficients and adjustment factors, and typical irrigation system efficiencies. The Web Site includes background information and explanations of PET and ET, crop coefficients, adjustment factors for landscapes, etc., as well as a Growers Guide that can be viewed or downloaded. The Web Site also contains the average monthly historic PET and rainfall for 19 Texas cities, and information on current and projected water use in Texas.

Presentations and trainings on how to use PET and the Web Site for agricultural irrigation scheduling are routinely provided by the TAEX, including scheduled short courses for municipal and utility personnel, and landscape professionals such as irrigation designers and installers, and golf course, athletic field and grounds managers. Texas ET is an integral part of TAEX's landscape irrigation program, including the San Antonio ET Pilot Project, where 60 homeowners are using PET for yard watering decisions, and the SAFE (sports athletic field education) program.

Initial funding was provided by TAEX in 1994 to initiate development of Texas ET. Since then, the Network and Web Site has been supported by outside funding and special projects.

South Texas Weather Station Network

The Texas Agricultural Experiment Station, Corpus Christi, operates a PET Network system with 16 weather stations located from Kingsville to Wharton in the Coastal Bend (Landivar, 1998). It is operated by Dr. Juan A. Landivar and County Extension Agents in Kleberg, Nueces, San Patricio, Bee, Calhoun, Victoria, Jackson, Matagorda, and Wharton counties. It records air and soil temperature, wind speed and direction, solar radiation, relative humidity, and rainfall. These variables are measured and reported on an hourly, daily and monthly basis. The system uses Campbell Scientific CR10 weather stations and data loggers with data transmission via telephone modem. Types of models used in conjunction with the network include cotton growth model, phenology models, and PET model.

Technical support is cited as a significant need along with training on software use and adequate recurrent funding. A technology transfer expert is needed to train users and maintain the integrity of the data.

The system was designed to facilitate the addition of new stations and link to other networks. Plans are being formulated to increase the network to 25-30 stations, expanding the network to the rice country in Southeast Texas and to distribute weather data through the internet.

South Plains PET Network

The South Plains PET Network, established in 1993, is based at TAES, Lubbock (Lascano, 1998). It involves a total of three weather stations located at Halfway, Lubbock and Lamesa. Data collected includes hourly and daily values of air temperature and humidity, solar irradiance, rain, and wind speed. All variables are measured at 2m height. Data reported include daily values of PET and degree-days for several crops. Area represented by coverage consists of at least three counties (Lubbock, Hale and Dawson) in which 40-50% of the land area is irrigated cropland.

Campbell Scientific standard weather stations normally used for agricultural meteorological applications together with supporting electronic interface, with LAN line or cellular connections. The method of information delivery

consists of a facsimile sent daily to subscribers of the PET service, and all data is available via a home page (<http://achilleus.tamu.edu/>). Close linkages exist with colleagues in Bushland/Amarillo (NP-PET Network).

The system has received one-year, small grant support by the High Plains Underground Water Conservation District No. 1 that was used to purchase a weather station. All other funds have been from the TAES Soil Physics program at Lubbock for maintenance and repairs for three weather stations. If funds permitted, the Network would be expanded to at least 10-15 weather stations and permanent funds are needed for maintenance and operation.

Other Comments

The present PET Networks have developed regionally out of need to provide daily information to farmers for irrigation scheduling as well as support research and education. Funding to date has been short term from a variety of sources. The necessary funding and impetus have not emerged to underpin the operation and maintenance of the existing weather networks across the state of Texas on a long-term basis. Despite the absence of a funded comprehensive statewide program to consolidate these systems and offer a sustainable support mechanism, there is every indication that present regional-based systems will continue to operate to assure continuous provision of data to the farmers who comprise much of Texas' \$19 billion/year direct agricultural production. The scientists and engineers who designed and operate these systems are to be commended for taking the initiative, despite severely limited funding, to devote considerable amounts of time and internal funding and work closely with regional clientele groups as partners to support these valuable efforts to date.

Acknowledgements

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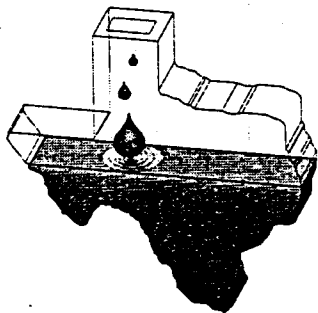
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